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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9014D.04

Released by:

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SUBMARINE MEDICAL RESEARCH LABORATORY

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SUMMARY PAGE

THE PROBLEM

To compare the visual perceptions and visual-motor coordinations under water for men who do and do not have extensive underwater experience.

FINDINGS

Tasks involving hand-eye coordination were performed much more accurately by men with diving experience than by men with no underwater experience; the latter rely completely on the distorted or false visual information in attempting to pick up or place objects under water. On the other hand, all men, regardless of underwater experience, tended to overestimate the sizes of objects under water.

APPLICATION

The results have important implications for the training of Navy divers. It appears from this study that divers require very lengthy periods of their routine activity before they show adequate adjustment to the visual distortions under water; on the other hand, great improvements should be achieved in short periods of time by specific training and specially designed activities. In addition, the excellent correlation between measures of hand-eye coordination and diver competence suggests that the former might be used as a test of the latter.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF12.524.004-9014D, Improvement of Vision and Orientation Underwater. The present report is No. 4 on that Work Unit. It was approved for publication on 12 Feb 1970 and designated as Submarine Medical Research Laboratory Report No. 612.

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ABSTRACT

Measures of a number of visual functions were performed on subjects with varying amounts of underwater experience. All measures of hand-eye coordination revealed a sizable influence of underwater experience, the more extensive the diving history, the greater the visual-motor skill. On the other hand, size estimates under water by men with diving experience differed little from those by men with none. Results for estimation of distances under water were intermediate, showing some—but not perfect—correspondence with the amount of underwater experience. The data suggest various additions to the training procedures for SCUBA divers which should facilitate their adjustment to underwater distortion.

EFFECTS OF DIVING EXPERIENCE ON VISUAL PERCEPTION UNDER WATER

INTRODUCTION

One of the many visual problems plaguing divers under water is the distortion in the optical image produced by the refraction of the light rays at the face mask. The distortion is, of course, a physical consequence of light energy passing from one medium, water, into another, air, in which its speed is greater. Various illustrations of these distortions are shown in Fig. 1.

The consequences of this refraction, for human vision, are many. First, when the light rays are refracted at the interface, a virtual image is formed at three-quarters of the distance of the object from the interface; that is, the rays seem to emanate from

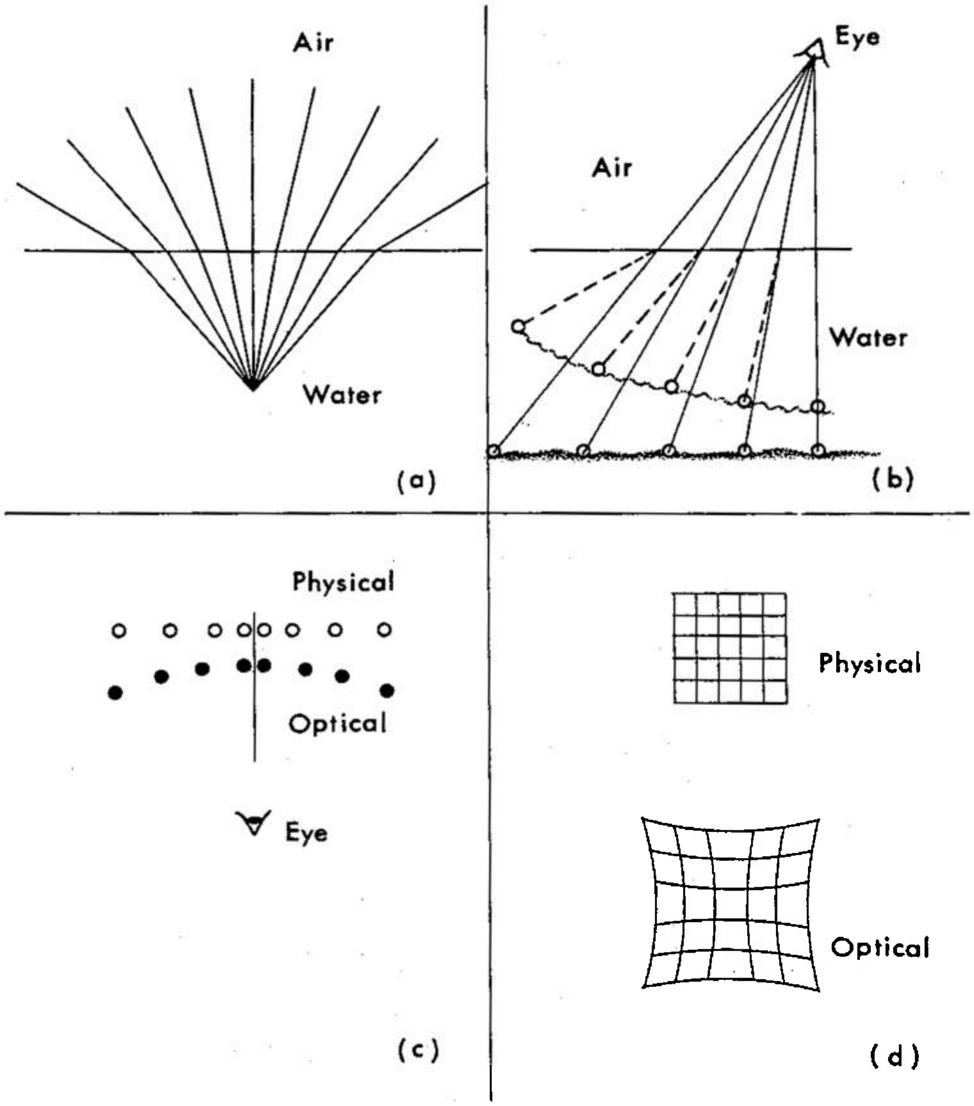

Fig. 1. Illustrations of refraction of light at the interface between air and water: (a) light rays emanating from a point in the water; (b) an illusion of the water becoming shallower as the bottom recedes from the viewer in air; (c) and (d) distortions in the shape of regular objects due to refraction.

a point at three-quarters of the distance to the real or physical point. This may cause a diver to underestimate the distances between himself and underwater objects.

Second, the retinal image formed from this virtual image is larger than the image would have been from the real object; the magnification factor is about 1.27 for the eye in a typical face mask. This may cause a diver to perceive the sizes of underwater objects as too large.

Third, since the amount of bending or refraction is dependent upon the angle of incidence (the greater the angle, the greater the refraction), the shapes and positions of the optical images on the retina are transformed. This transformation may cause changes in the perceived size and location of objects under water.

Finally, since objects are not physically located where they appear to be, optically, hand-eye coordinations and visual-motor skills of a diver may be disrupted.

Whether or not disruption of visual perception will occur as a function of these refractive changes is, in each case, an empirical question. Visual perceptions cannot always be predicted from what appear to be obvious retinal image changes. Two well-known phenomena in air illustrate the point. Size constancy refers to the fact that the perceived size of objects in our visual world remains the same despite the distance of the object from the observer. Thus, the retinal image of a person, for example, may shrink by a factor of 100 or a 1000 as the person walks away, but he does not shrink in perceived size.[1]

Second, the fact that humans eventually can respond appropriately to the physical object, disregarding the distorted stimulation, is well documented.[2] Subjects have, after considerable time, learned to fence, mountain climb, and ski, while wearing lenses that invert the entire visual scene.[3] The changes that occur in underwater visual perception thus can be expected to vary with the specific visual task to be performed and with the amount of underwater experience of the subject.

In this study, a number of measures were made of three visual functions under water: size perception, distance perception, and hand-eye coordination. A large number of subjects whose underwater experience varied from none to that of a qualified Navy diver were tested. Included among them were students from a Navy SCUBA Class, who were tested periodically during their training.

TEST BATTERY

I. HAND-EYE COORDINATION

Hand-Eye Table

Coordination was measured on a specially constructed table, two feet square, with a flat white top on which four standard positions were marked by crosses. The subject's task was to mark, on the underside of the table, the positions indicated on top. He was thus not able to see his own hand while marking, but he could see the designated positions. The table top is illustrated in Fig. 2; both the physical locations and optical positions are indicated. Apparent positions are shifted both toward the subject and towards the edges of the table.

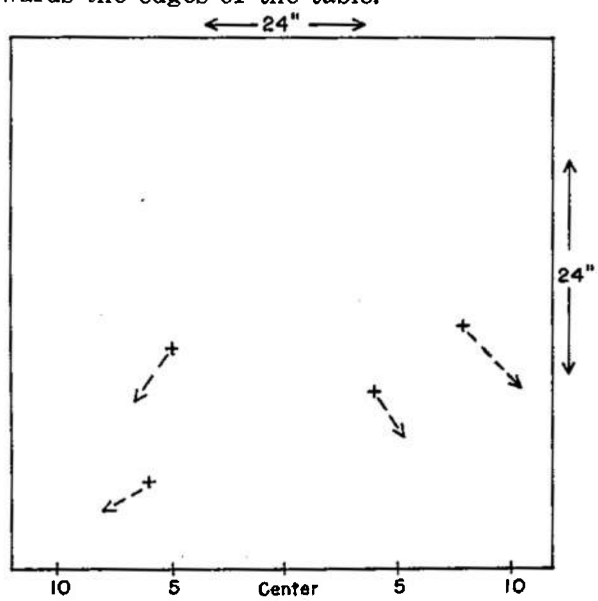

Fig. 2. Scale drawing of the top of the hand-eye table, indicating the physical locations of the targets (+) and the position of the optical image (arrow-head). The average optical displacement of the four targets is 2.2 inches toward the subject and 1.7 inches toward the edges of the table.

A testing session consisted of two marks by the subject at each of four positions. The order of presentation of positions was randomized and given to the subject verbally. He was instructed to return his hand to his side after each mark.

This test has been used extensively in our laboratory since 1967; it has proved very reliable and is very similar to measuring devices used in air.[4] Nonetheless, other measures of hand-eye coordination or of visual-motor performance were included in the battery.

Placing Task

The subject was asked to place a chess-piece in a target-ring located on one of the squares of a checkerboard grid constructed of one-half inch black and white squares. After the subject had looked at the target, his eyes were covered while he attempted to place the chess-piece. The ring was randomly put at eight different positions on the board. Data were recorded to the nearest quarter-inch.

This test differs from the hand-eye table in that the subject can see neither his hand nor the target while making his placement of the chess-piece.

II. POSITION IN DEPTH

Several measures were made of the subject's ability to judge the distance of an object from himself. In two of the tests, the subject and target were in the water and he was asked to position another object so that it appeared at the same distance from himself as the target. In the third, the subject was in the air and viewed the underwater object through a porthole.

Manual Adjustment to a Nearby Target

In this apparatus, a vertical rod hung in front of the subject at a distance of 13.8 inches from him. A second identical rod was hung from a track parallel to the line of sight of the first rod; the second could be moved back and forth. A screen blocked the subject's view of the second rod when his head was in a chin rest. His task was to position the second rod so that it appeared to be in the same plane as the one he could see. This test is thus very similar to the hand-eye table except that the distortion is in only one dimension rather than two.

Adjustment of an Air Comparison to a Distant Target

In this test, the visual target, a four-inch square of white metal, was suspended in the water by a fine wire at a distance of five feet from the subject. Another target, of amorphous shape but similar size, was hung outside the pool from a line on a pulley system that ran perpendicular to the porthole in the above-ground pool. The pulley system could be manipulated by the subject in the water.

The subject knelt by the porthole and turned his head back and forth to compare the target in air with the target in the water; he viewed the latter through a circular aperture—set up in the pool—equal in size to that of the porthole. His task was to adjust the distance of the target in air so that it appeared to be at the same distance from him as the one in the water.

These two tests of position in depth share similar features, but they are also distinct in two important ways. First, in one test, the comparison target is presented **tactually** and is never seen, while in the other test, the comparison target is a **visual** one in air. Second, one test involves visual-motor manipulations within arm's reach of the subject. The second test presents a remote target for which the adjustment of the comparison could draw on no prior motor skill.

Judgments of Relative Distance

This test was given only to the students in the SCUBA class. The subject was provided with a standard target, a four-inch square, that was positioned two feet from his headrest. A movable target, also four inches square, was positioned at eleven discrete distances between 1 and 16 feet.

The subject was instructed that the distance between the stationary target and himself was one standard unit, and that he was to estimate how many standard units there were between the movable target and himself. The standard was always in air; the movable target was presented both in air and in the water.

During a given session, each subject made

judgements of the relative position of the movable target at five different distances, randomized across subjects and trials. Thus, a given subject did not necessarily make judgments at the same distances from one testing session to another or at the same distances as the other subjects. This was done to preclude learning a stereotyped response.

III. PERCEPTION OF SIZE

Memory for Size of Coins

Four coins, a dime, penny, nickel, and quarter, were chosen as the memory standards. A series of 16 aluminum disks were provided whose diameters varied from 0.5 to 1.3 inches, well encompassing the range of diameters of the four coins. The subject's task was to select from the complete set, the disk most representative in diameter of a dime, penny, nickel, and quarter.

Memory for Size of Magazines

This test is essentially the same as the coin test except that larger memory standards were employed. Reader's Digest, Newsweek or Time, and Life or Look were the standards to be selected by the subject from a set of aluminum rectangles that varied in size.

SUBJECTS

Subjects were Navy men, most of whom were chosen at random from volunteers for the experiments. In addition, a group of qualified Navy divers and a group of students from a Navy SCUBA Class were tested.

The qualified Navy divers were attached to the Submarine Escape Training Department of the Naval Submarine School, Naval Submarine Base, Groton, Conn., and thus under the command of one man. This officer was asked to rank the men for competence or proficiency under water. He apparently found the task an easy one; his judgments were augmented with statements such as "one of the best—I'd trust him with anything" to "Brand new—virtually no experience." These rankings provide additional data with which to compare the measures made on the qualified Navy divers.

PROCEDURE

All subjects were given all tests both in air and in the water. Half of the subjects were tested first in air, the other half began in the water. Water tests were given in an above-ground pool, four feet deep, specially outfitted with portholes for underwater viewing; the testing was performed with the subject in the pool, wearing a weight belt, face mask, and snorkel. In air only the face mask was worn. Subjects with no underwater experience were first instructed in the use of the mask and snorkel and allowed to practice for a few minutes before testing.

Subjects with underwater experience were tested more than once. The Navy divers were tested early in June and again in August after extensive summer diving. The SCUBA students were tested originally before their first class and then weekly throughout the course of their four-week training.

RESULTS

HAND-EYE COORDINATION

Hand-Eye Table: This test, which measures the subject's ability to position his unseen hand at a designated visible location under water, has been used extensively in a large number of experiments. The data from these various experiments have been collated in Tables I and II; these are the results of the first attempts at the test by various subjects who have been grouped according to their underwater experience.

Table I. Amount of Underwater Experience and Original Distortion in the Third Dimension on the Hand-Eye Table.

Subjects	Number	Amount in inches
Never Used Snorkel, Mask	41	2.20
Occasionally Used Snorkel, Mask	69	1.97
Frequently Used Snorkel, Mask	20	1.30
SCUBA Class		
No prior SCUBA experience	14	1.27
Some SCUBA experience	12	1.04
Drop-outs	9	1.37
Navy Divers		
June	6	0.98
August	8	0.80

Table II. Amount of Underwater Experience and Lateral Distortion on the Hand-Eye Table.

Subjects	Number	Amount in inches
Never Used Snorkel, Mask	41	0.21
Occasionally Used Snorkel, Mask	69	0.24
Frequently Used Snorkel, Mask	20	0.32
SCUBA Class		
No prior SCUBA experience	14	0.42
Some SCUBA experience	12	0.45
Drop-outs	9	0.41
Navy Divers		
June	6	0.36
August	8	0.13

It is possible to make errors in two different dimensions on this test: (1) the distance between the subject and the designated position, called the third dimension, and (2) the distance from the designated position in a frontal plane, called the lateral dimension. In Table I, the data from the third dimension reveal a systematic relationship. Subjects with no underwater experience make large errors; furthermore, the magnitude of the error is almost exactly the same as would be predicted from the amount of optical distortion. As underwater experience increases, the amount of distortion or error revealed on the test decreases. The relatively good performance by men entering SCUBA class presumably indicates considerable underwater experience; they must feel at ease in the water or they would not volunteer for the course. The course is an exacting one; some men dropped out after the first few days, the scores of these men were not as good as those for the rest of the class.

The results for the qualified Navy divers, while certainly the best, still showed an average error of 0.8 inch in August. However, individual differences among this group were sizable. Scores ranged from 0.11 to 1.71, and the mean is somewhat inflated by the larger scores; the median was 0.62 inches. Furthermore, the amount of underwater experience of the divers varied from about 1000 hours over a 10-year period to very little for those just recently qualified.

Comparable data for the lateral error is tabulated in Table II. All of the errors, regardless of the group involved, are small and do not approach the amount predicted by optical distortion which should average a 1.7 inch shift toward the edges of the table. It seems likely that head movements, right and left, are vitiating much of the lateral optical distortion. Nevertheless, it is clear that errors in this dimension are not correlated with underwater experience.

Placing Task: The data resulting from subjects' attempts to place an object at a specific position on the checkerboard are given in Table III. A large amount of data on inexperienced subjects was available from another experiment.[5] The average placements by these subjects were one inch closer to themselves in the water than in the air and were displaced towards the edges of the checkerboard by over ½ inch in the water. The data for the experienced divers show less error, once again specifically in the third dimension.

A scale drawing of the actual locations of the target positions and the placements is given in Fig. 3. The water data for the inexperienced subjects clearly show the optical distortion; compare the data points with Fig. 1c. The divers' placements in the water, on the other hand, cluster with the air responses.

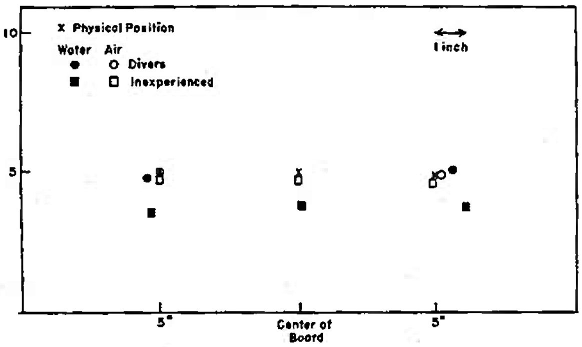

Fig. 3. Scale drawing of the physical positions of the target in the placing task and of the average responses by inexperienced subjects (□) and by divers (0), both in the air and in the water.

POSITION IN DEPTH

When the visible rod in the water was 13.8 inches away, the experienced divers set the invisible rod at 12.2 inches. In air, their setting for the same task was 13.7 inches, a

difference due to distortion of 1.5 inches. This can be compared with values for other

Table III. Mean Shifts in Placing Errors (Air-Water) for Different Groups.

Subjects	Toward Self	Toward Edges
Experienced Divers		
June, N=6	−.56	.73
August, N=8	.32	.16
Inexperienced Subjects, N=72	.98	.64

subjects in Table IV. The divers' underwater responses are more congruent with the physical location than are the responses of those with no underwater experience; they have compensated for approximately one-half of the theoretical distortion.

Similarly, Navy divers perform better than inexperienced subjects in adjusting the position of the visible target in air to that of one in water. These data are also given in Table IV. In this case they show compensation amounting to about two-thirds of the theoretical optical distortion.

Table IV. Distortion in Apparent Distance of Objects.

Subjects	Adjustment by Hand of Nearby Rod	Adjustment by Pulley of Distant Visual Target
Theoretical Optical Position	10.6 inches	45 inches
Inexperienced Ss	11.4	48
Navy Divers	12.2	55
Physical Position	13.8	60

PERCEPTION OF SIZE

The disks selected by the various subjects as equal in size to the four coins are presented in Table V. The data for the inexperienced subjects are taken from another investigation[6] and are comprised of estimates by two groups of ten subjects each. Group 1 made the visual estimates immediately upon entering the water; Group 2 made visual estimates after two to three minutes in the water, during which time they were allowed to look at and feel the coins.

Table V. Size Estimates of Coins by Subjects with Varying Underwater Experience (Diameter in Inches).

	Dime		Penny		Nickel		Quarter	
Subjects	Air	Water	Air	Water	Air	Water	Air	Water
Standard Diameter	.70	.55	.75	.59	.84	.66	.95	.75
Navy Divers N=6	.69	.56	.79	.60	.85	.70	1.00	.87
N=8							.93*	.85*
SCUBA Class N=26	.68	.55	.76	.60	.85	.67	.98	.83
Inexperienced Subjects N=20	.69	.55	.77	.61	.84	.68	.98	.80
Group 1 N=10		.55		.60		.64		.75
Group 2 N=10		.56		.61		.71		.84

*Only the quarter was used on the retest in August.

The estimates made in the air are very close to the actual physical sizes of the coins for all groups of subjects. In water, estimates are close to the theoretical optical size; that is, the diameter which yields the appropriate physical diameter when multiplied by the magnification factor. Differences among subjects grouped according to underwater experience are very small. Only the data for the quarter suggest any systematic relationship between experience and size estimates; in line with expectations from adaptation to underwater distortions, estimates of a quarter for experienced divers are slightly larger than for inexperienced divers. However, even this small difference has disappeared for the group of ten inexperienced subjects who spent two to three minutes in the water before the visual test.

Table VI. Size Estimates of Magazines by Subjects with Varying Underwater Experience (Length in Inches).

	Reader's Digest		Newsweek or Time		Life or Look		
Subjects	Air	Water	Air	Water	Air	Water	
Standard Length	7.4	5.8	11.2	8.8	13.6	10.7	
Navy divers N=6	8.3	6.5	12.0	10.2	13.8	13.0	
N=8	8.4	6.7	12.2	9.8	14.5	12.4	
SCUBA Class N=26	8.2	6.4	11.3	8.8	15.0	11.6	
Inexperienced Subjects N=20	7.8	6.3	11.2	8.7	13.8	11.6	
	Air/Water Size Ratios						Mean
Navy divers	1.26		1.21		1.11		1.19
SCUBA Class	1.28		1.28		1.29		1.28
Inexperienced	1.24		1.29		1.19		1.24

Theoretical = 1.27
Mean of 9 Ratios = 1.24 = 11% compensation

Comparable estimates for the sizes of magazines are listed in Table VI. This task was apparently more difficult for the subjects, since the estimates in air differ from the physical size much more than did the coin estimates. This probably reflects less familiarity with the magazine sizes; in fact some subjects complained that they never read magazines and really had no idea of their size.

Nevertheless, the results are essentially the same as those of the coins. The estimates in the water are much closer to the optical size than to the physical size, and this is generally true for all groups regardless of experience. Air to water ratios, given in the lower half of Table VI, do not vary systematically with underwater experience; the overall mean of 1.24 differs only slightly from the theoretical ratio, based on refraction, of 1.27.

EXPERIENCE OF QUALIFIED NAVY DIVERS

Rank order correlations were calculated between the scores made by the qualified Navy divers and the rating of their underwater competence by their commanding officer. A score was compiled from all the measures of hand-eye coordination; the correlation between this measure and underwater proficiency was .85. Thus, the more competent the men are rated to be underwater, the better they do on our tests of hand-eye coordination.

The various tests of the perception of size were similarly compiled into single scores; the correlation between this measure and underwater proficiency was —.03, revealing no relationship whatsoever.

The correlation between the measures of depth perception and underwater proficiency of .68 was intermediate.

REPEATED TESTING OF SCUBA CLASS STUDENTS

The data on students presented thus far have been the initial measures made when they first entered the SCUBA Class. These tests were repeated once a week for three weeks while the students were undergoing the intensive, daily, underwater training required for the Navy class. The data for men who entered the class with prior SCUBA experience were compiled separately from the data of those with no prior experience.

Hand-Eye Coordination

Figure 4 presents the average errors on the Hand-Eye Table for these students over the four-week period. The initial distortion was slightly over one inch at the beginning and slightly under one inch at the end. The men with prior SCUBA experience showed less distortion throughout than did those with none, but neither group improved very much during the entire month.

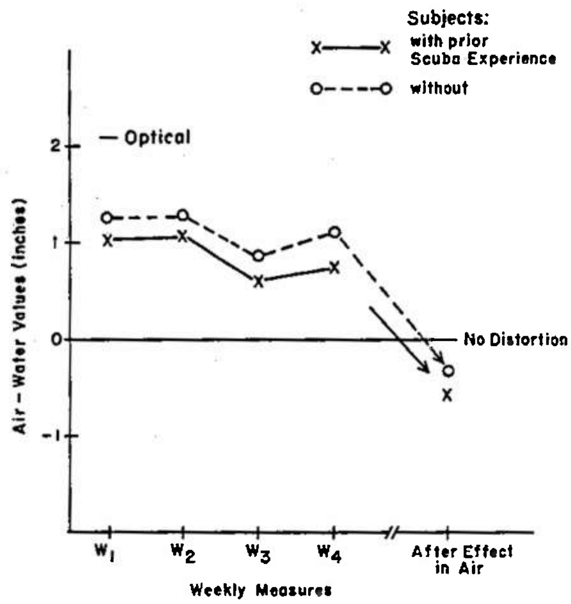

Fig. 4. Responses on the hand-eye table by students in SCUBA Class over the four week period.

Size-Estimates

The average size estimates for the coins are given at the top of Fig. 5 for men with and without prior SCUBA experience. There is a small difference between the two groups originally which tends to disappear over time; however, there was little change in the estimates of either group during the four weeks. The data for the individual coins are pictured at the bottom of Fig. 5 for all the subjects. Once again, there is little change over time and the after-effect is small in size.

Comparable data for the size estimates of the magazines are given in Fig. 6. The aver-

age estimates for all three magazines, at the left, reveal no differences due to prior underwater experience. At the right, the estimates for all 26 students have been compiled separately for each magazine. Sizes chosen under water are much smaller than those in air throughout the four-week period. Furthermore, they are quite comparable to the theoretical, optical values of 1.27. Ratios of the sizes selected in air to those picked under water for the first week are 1.28, 1.28, and 1.29 for Reader's Digest, Time, and Life respectively. Comparable values for the three magazines on the fourth week are 1.27, 1.21, and 1.25. All ratios were thus much more influenced by optical factors than physical size; ratios based on the latter would, of course be 1.0.

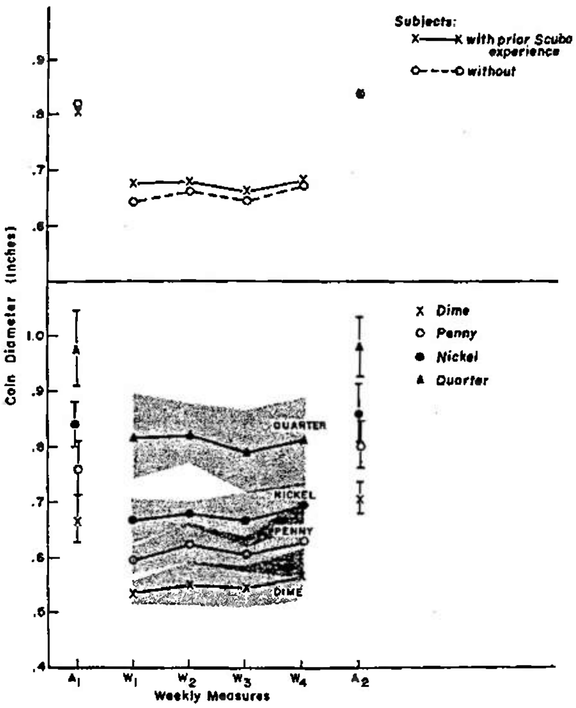

Fig. 5. Average sizes of disks selected as representative of various coins by students in SCUBA Class over the four week period. Average selections by students with and without prior SCUBA experience are given at the top. Means and standard deviations for individual coins, for all 26 subjects, are shown at the bottom.

Distance Judgments

The distance judgments made by the experienced and inexperienced students are shown in Fig. 7 for each of the testing conditions. Subjects, on the average, overestimated the distances of the target both in air and in water. The students with prior SCUBA experience made somewhat larger estimates throughout than did those without a diving history; however, this occurred in both air and water and cannot be attributed to underwater experience.

Data for the different testing conditions are plotted together in Fig. 8 in order to facilitate comparison. Data for the two groups of subjects have been combined, since prior SCUBA experience did not influence judgments. Differences among conditions are very small: the data for the two tests in air are virtually identical; judgments made during the second, third, and fourth tests in water are also very similar; furthermore, the judgments from these water trials are comparable to those made in air. Only the responses from the first test in water reveal any differences; these judgments are somewhat larger than all the rest.

DISCUSSION

The major outcome of this assessment of the visual performance of men under water is the sizable influence of prior underwater experience on hand-eye coordination. The visual-motor performance of men with no underwater experience is completely disrupted; that is, they rely on the distorted optical image. The responses of men with extensive time under water are quite adequate for the physical conditions; they have learned to adjust or have adapted to the transformed underwater stimulation. In between these two extremes there is a regular progression of improvement in visual-motor skills with increasing familiarity with the water. Yet, even within the select group of qualified Navy divers, there are sizable individual differences —the more competence under water, the better the scores on our tests of hand-eye coordination.

One might infer from these facts that adaptation to underwater distortions occurs naturally and quickly for men working or

playing in the water. In fact, our original purpose in testing the students from SCUBA class was to map the course of this adaptation as it automatically occurred. The data, however, revealed that no matter what aspect of visual performance was tested, the men in the classes improved very little during the course. Apparently some adaptation is achieved fairly quickly and automatically, but the ideal response of complete adaptation (congruence with the physical rather than optical location of objects) requires extensive underwater training.

This conclusion may be compared with the data from numerous studies employing distorted visual stimulation performed in air. The results of many investigations are presented in terms of highly significant differences between pre- and post-exposure tests; however, assessing the data in terms of magnitude of compensation achieved frequently reveals small effects that may be of no practical significance.[7] Adaptation times in these reports vary from a few minutes to an hour or so.

Nonetheless, 100% compensation can be achieved, as the demonstrations of Stratton and Kohler attest.[3] The time intervals required for complete adaptation to inverting prisms were long—continuous wearing for weeks or months. One hundred percent adaptation to lesser distortions has also been shown in a few cases in air, but the time periods are shorter than for complete optical inversion. Held and Bossum[8] found that 8 out of 15 subjects showed 100% compensation within a few days; Mikaelian and Held[9] had three unusual subjects who adapted completely in two hours; Pick and Hay's[10] subjects achieved 86% adaptation in three days, when measured by kinesthetic localization.

The conclusion from investigations in air is thus the same as from this study in water. Behavior does change significantly after relatively short periods of exposure to the distor-

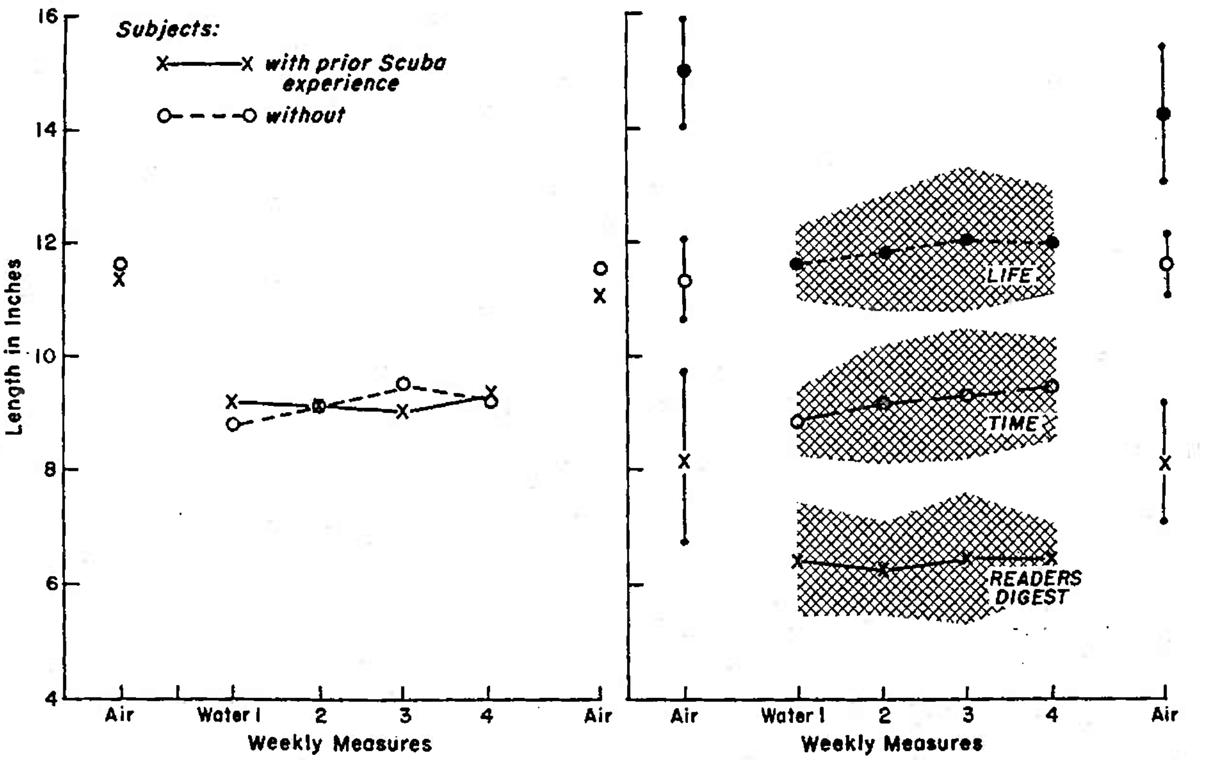

Fig. 6. Average sizes of rectangles (length) selected as representative of various magazines by students in SCUBA Class over the four week period. Average selections by students with and without prior SCUBA experience are given on the left. Mean and standard deviations for individual magazines, for all 26 subjects, are shown on the right.

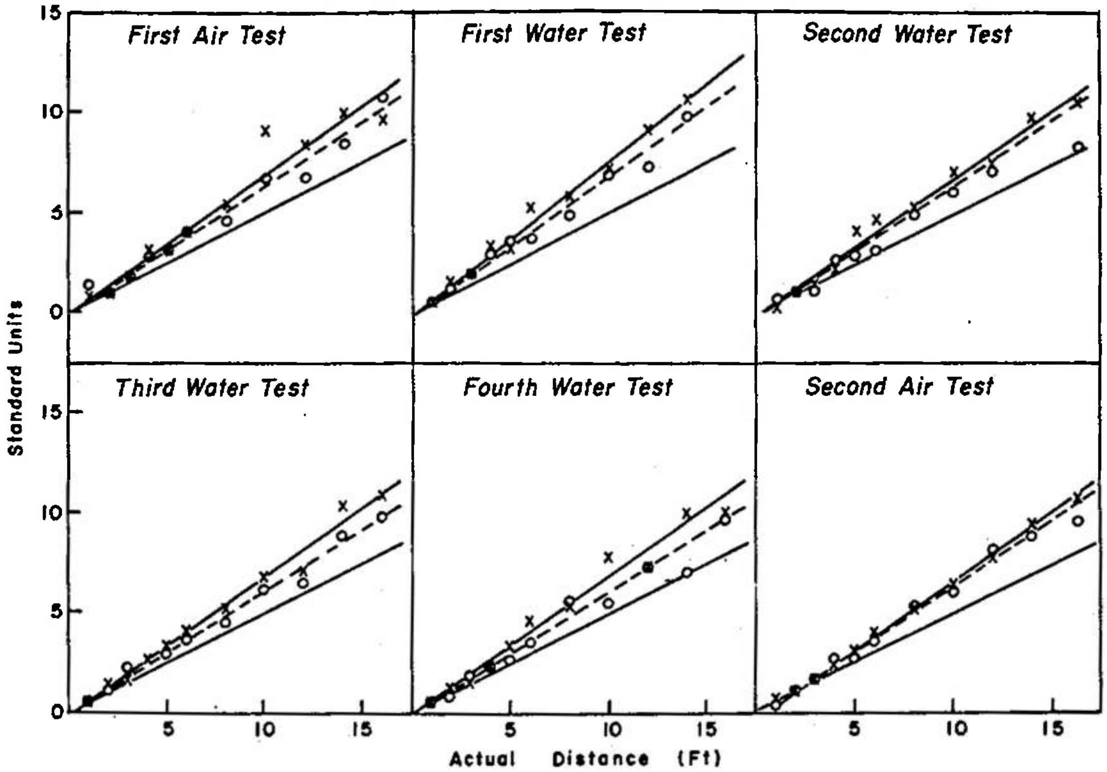

Fig. 7. Distance estimates made by students in SCUBA Class in the various weekly tests. (Prior SCUBA experience, X; No SCUBA experience, 0). One standard unit was actually 2 feet; the light line in each of the figures thus indicates physical equality.

tion, but the actual magnitude of compensation may be small—responses are governed to a much greater extent by the optical image than by the physical position of the object when the two conflict. Only with extensive time periods, however, can complete congruence with physical position be achieved. This usually requires days, weeks, or months of exposure.

The investigations performed in air have also indicated that some types of activity during exposure to distortion are much more effective than others in producing adaptation.[11] The same conclusion may be reached from a comparison of our results on subjects under water. In our first investigation of distorted stimulation under water,[12] subjects were given 30 minutes of specially designed visual-motor activities under water. A group of novice divers performed better under these conditions than did the students from SCUBA class after four weeks of extensive underwater training.

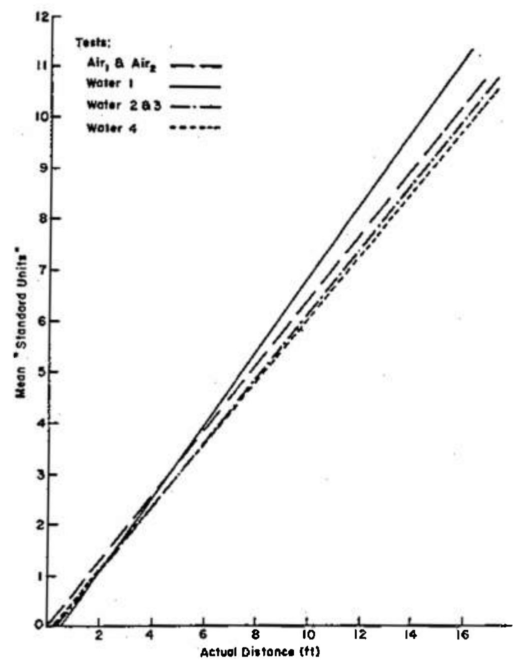

Fig. 8. Comparison of distance estimates for all 26 students on different occasions.

It would appear that there is tremendous room for improvement in hand-eye coordination in beginning divers and that specific training or specially designed activities could be added to the curriculum of SCUBA divers to facilitate this improvement. Further research is going on toward this aim.

All of the foregoing discussion has referred exclusively to hand-eye coordination or to motor responses that are dependent upon the visual input. The test battery employed in this investigation included a number of tests which require only visual judgments and no motor manipulations by the subject. This is true of the two tests of the perception of size, of the relative distance test given the SCUBA class, and, to a lesser extent, of the distance comparison using the pulley system.

The judgments of distance revealed experienced divers to be better than individuals with no underwater experience, in the sense that their underwater data were more consistent with their estimates in air. Even the students from the SCUBA class, whose performance on other tests showed little adaptation, made distance judgments under water that were comparable to their judgments in air, after the first week. The possibility exists, however, that these distance judgments may represent a different type of adaptive phenomenon than does hand-eye coordination; there is no after-effect apparent in the air data and the judgments at first show overestimation under water rather than underestimation. While this is entirely consistent with previous data on the perception of longer distances under water,[13] the physical condition underlying the distorted perception is not refraction.[14]

The tests of size perception showed a completely different result than those of hand-eye coordination and depth perception; all subjects showed reliance on optical information and the differences between experienced and inexperienced subjects were small or nonexistent. Inexperienced subjects very rapidly achieve the same results as experienced divers—within a few minutes in the water. Furthermore, the correlation between underwater competence ratings of the Navy divers and their size estimates was essentially zero.

All this suggests that the perception of—size or perhaps any purely visual phenomenon—represents a distinctly different process than does hand-eye coordination; furthermore, the plasticity of this process may be negligible compared to that of hand-eye coordination. Similar suggestions have been made by Pick and Hay[10] and by Held[15] on the basis of their investigations performed in air. The practical implication is that objects will always appear too large to divers no matter how experienced they are, and that they must consciously correct for this in order to make accurate size estimates under water.

One final application of these results should be noted—the possibility that a measure of hand-eye coordination might be developed as a test for a diver's underwater proficiency. An independent measure of competence is of obvious importance in many situations since divers may overestimate their diving ability in order to gain access into a desired program. The possibility of measuring competence is attested to by the relationship between scores on the hand-eye test and both general underwater experience and the competence ratings of divers. The fact that the scores on the test by dropouts from SCUBA class were poorer than those of the rest of the men yields further support. Research continues on this possibility.

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13. ABSTRACT

Measures of a number of visual functions were performed on subjects with varying amounts of underwater experience. All measures of hand-eye coordination revealed a sizable influence of underwater experience, the more extensive the diving history, the greater the visual-motor skill. On the other hand, size estimates under water by men with diving experience differed little from those by men with none. Results for estimation of distances under water were intermediate, showing some--but not perfect--correspondence with the amount of underwater experience. The data suggest various additions to the training procedures for SCUBA divers which should facilitate their adjustment to underwater distortion.

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